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STATISTICS OF THE REGION OF LACERTA OB1

by George Coyne, S. J., Jaylee Burley Mead, and Michele Kaufman

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ABSTRACT

Spectral classes and photographic magnitudes have been determined for 3621 stars in the region of the association Lac OB1. Astrophotometer measures of images on glass reproductions of the Palomar Sky Survey plates have been used for the photometry, and spectral classes have been determined by using color equivalents according to the Tikhoff method. The star counts indicate that there is an excess of early A stars on the main sequence in the concentrated region of the association as compared with the dispersed region. Also, the total area of our survey shows a deficiency of stars later than F5 as compared with counts in nearby Selected Areas. It is recommended that membership determinations be made for the A stars that constitute the clustering in the concentrated region of the association.

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STATISTICS OF THE REGION OF LACERTA OB1*

by
George Coyne, S. J.,†
Jaylee Burley Mead,‡
and
Michele Kaufman§

INTRODUCTION

Evolutionary effects in the region of the association Lac OB1 have been investigated by Blaauw (1958). He noted that the region between α (1900) = 22^h 26^m and 22^h 46^m and δ (1900) = $+36°$ and $+41°$ contained most of the O-B stars, and he referred to this as the most concentrated region of the association. Examining the distribution of association members in the spectral range 09 to B3, he found that the 09 to B1 stars are present only in the most concentrated region of the association. In addition, the B stars in the dispersed area of the association are systematically brighter than those in the concentrated area. Blaauw's suggestion that the B stars in the dispersed area are slightly evolved is corroborated by Crawford's (1961) Hβ photometry of 18 B2 to B3 stars in the dispersed area.

Hardie and Seyfert (1959) observed 77 B5 to A7 stars in the concentrated area of the association. Most of the A stars (37 of 43) lie above the zero-age main sequence. No velocities are available for these stars, and they were selected as possible members because of their presence in the concentrated area of the association. Therefore, the A stars above the main sequence may simply be foreground stars and may not indicate an evolutionary effect. From Hβ photometry of 16 of the Hardie and Seyfert stars, Crawford (1961) concludes that nine of 11 stars above the main sequence are probably non-member foreground stars. Howard (1958) found an excess of stars of spectral type A from counts in the Henry Draper Catalog. A survey by Ramberg (1957) overlaps a strip of about 1 degree in declination along the northern edge of our survey.

The purpose of the present study is to determine statistically the distribution of spectral types A0 (and later) in the region of the association Lac OB1 in order to see if there is any clustering and to determine the relative distributions in the concentrated area as compared with

*A summary of this work entitled "Survey of the Region of Lacerta OB1" appears in the Astronomical Journal, Feb. 1969.
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the dispersed area. For most of the stars observed, neither proper motions, radial velocities, nor distances are available; hence it is impossible to determine membership. Should the present study reveal any clustering or significant density variations between the concentrated and dispersed areas of the association for the stars of a given spectral class, then subsequent studies would be required to determine membership for these select groups of stars.

OBSERVATIONS

The region investigated is indicated by the areas enclosed by solid lines in Figure 1. The total area of the sky covered is 91.42 square degrees. The concentrated area of the association as defined by Blaauw corresponds almost exactly to Area A (centered at $\ell^{II} = 95°$, $b^{II} = -17°$). Photographic magnitudes and spectral classifications were assigned for virtually all stars with $8.5 < m_{pg} < 13.0$ in areas A, B, and C. In a few cases it was impossible to measure double stars because of their proximity to one another. The distance modulus of Lac OB1 is variously given as $8\overset{m}{.}3$ (Morgan, Whitford, and Code, 1953), $8\overset{m}{.}4$ (Hardie and Seyfert, 1959), and $8\overset{m}{.}6$ (Blaauw, 1958). If we take a distance modulus of $8\overset{m}{.}4$, then, neglecting absorption, an A0 star on the zero-age main sequence will have $m_{pg} \cong 9.8$ and a G0 star will have $m_{pg} \cong 13\overset{m}{.}7$. A reasonable mean value for the total visual absorption is about $0\overset{m}{.}3$ (Blaauw and Morgan, 1953; Hardie and Seyfert, 1959). The magnitude range of this survey will therefore cover main-sequence stars earlier than approximately F5 at the distance of the association.

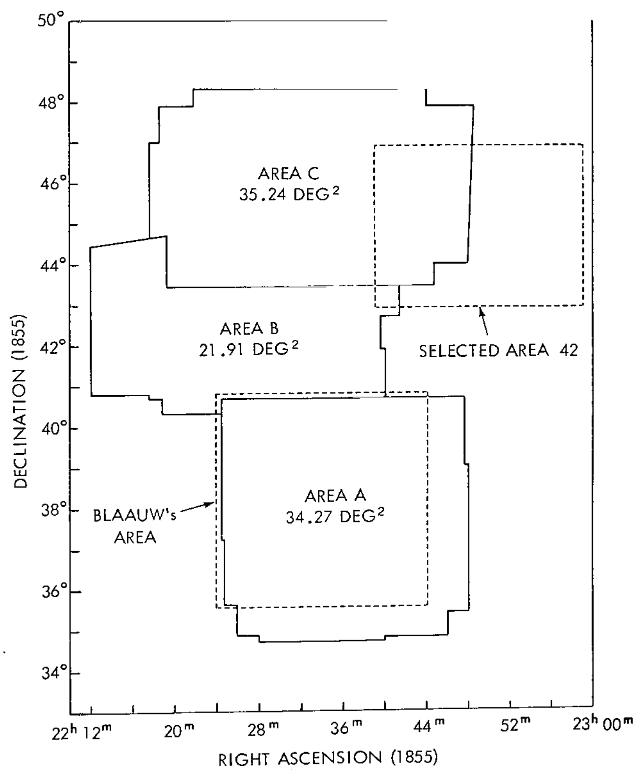

Figure 1—Lac OB1, areas surveyed.

Spectral classes were determined by using color-equivalents according to the Tikhoff method (Tikhoff, 1937). This is a method of out-of-focus photography for obtaining the spectrum of a star as a continuous series of concentric rings of varying density. The 16-inch Metcalf refracting telescope of the Agassiz Station of Harvard College Observatory, which has large chromatic aberration, was used for obtaining this plate material. An opaque occulting disk, 8 inches in diameter, was placed over the center of the objective lens so that an out-of-focus image appears as an annulus. For light of a given wavelength, the radius of the annulus is proportional to the diameter of the occulting disk and the distance of the plate from the true focus for that particular wavelength. The telescope was focused for blue light, and Kodak 103 a E emulsions were used. This emulsion has a greater sensitivity to red light and decreases in sensitivity between wavelengths of 5000 and 5500 Å, which helped in the separation of the blue and red light. Any B star, therefore, appears as a bright central dot (representing the blue light) with a much less dense cloud about the dot (representing the red light); a K star appears as a dense ring. By the general appearance of the Tikhoff images—particularly by estimates of the relative densities from the center to the edge of the image—it is possible to classify a star. Standards for this classification were taken from Kapteyn's Selected Area 42 which overlaps the region under investigation as indicated in Figure 1. The Bergedorfer Spektraldurchmusterung gives spectral classes for all stars with $m_{pg} < 12.5$. A comparison of the Bergedorfer, Henry Draper and MK spectral classifications (taken from Fehrenbach, 1958) is given in Table 1. The B-V colors there are from Harris (1963). All stars were, therefore, classified by comparing their Tikhoff images with Tikhoff images of stars of about the same magnitude for which objective prism classifications are available in the Bergedorfer Spektraldurchmusterung.

Table 1

Comparison of Spectral Classification Systems.

Bergedorfer	HD	MK	B-V (main sequence)
A0	A0	A0	0.00
A2	A2	A2	0.06
A6	A5	A5	0.15
A8	A8	A8	0.25
F0	F0	F0	0.33
F2	F2	F2	0.38
F4	F4	F5	0.45
F7	F8	F8	0.53
G0	G0	G0	0.60
G1	G2	G2	0.64
G3	G5	G6	0.69
G6	G8	G8	0.72
G8	K0	K0	0.81
K0	K2	K3	0.98
K4	K5	K5	1.18

The assignment of color-equivalent spectral types is affected by variations in reddening and by the variation of color with luminosity class for stars of a given spectral class. The data given by Harris (1955) and by Hardie and Seyfert (1959) suggest that reddening does not vary smoothly with position in Lac OB1, although Johnson (1953) indicates that the color excess is uniform within 3 degrees of 10 Lac [22^h $32^m.8$, +38° 22' (1855)]. In addition to apparent variation of reddening within the association, there exists the further problem that a given star in the field may not be at the distance of the association and hence undergoes an unknown amount of reddening. If we assume that the amount of reddening forms a random distribution about some mean value and that, for a large sample, fluctuations will average out, then one can apply a uniform reddening for all stars of a given magnitude and color, since such stars are generally at the same distance. On this assumption, classification of all stars by comparison of their Tikhoff images with the Tikhoff images of standard stars generally gives a color-corrected classification. We have neglected the variation of spectral type with luminosity class for stars of a given color. This omission is significant (greater than or equal to 3 subclasses) only for spectral classes later than G0 (see Harris, 1963; Allen, 1963). One should therefore attach lower weight to our statistics on spectral types later than G0 than to our statistics on earlier types.

In order to estimate the accuracy of the classifications in the area which overlaps directly with Selected Area 42, classifications of 128 standards in Selected Area 42 were made from their Tikhoff images, and the differences from the Bergedorfer classifications were determined. No systematic difference was detected. From these measurements we find that a probable error of 3.5 subclasses is associated with the determination of spectral classes from the Tikhoff images, where the probable error is defined as

$$0.6745 \left(\sum \frac{\Delta^2}{n}\right)^{1/2}$$

and Δ is the difference between the Bergedorfer classifications and those from the Tikhoff images.

Altogether four 8- by 10-inch plates of Tikhoff images cover the total area surveyed. Selected Area 42 overlaps with but one of these plates; therefore, transfers had to be made to the other plates by using secondary standards. In order to estimate the accuracy of these transfers, approximately 30 stars in the overlap region of each pair of overlapping plates were measured and the difference in the classification on the separate plates determined. In no case was there a systematic difference greater than 1 subclass. This measure of systematic difference was taken as

$$\sum \frac{\Delta}{n},$$

where Δ is the difference in the classification on the two separate plates and n is the number of stars measured in the overlap region. The average probable error associated with these transfers is 3 subclasses, the largest probable error 3.2 subclasses. The probable error for each of the individual transfers is given in Table 2.

Table 2

Plate Transfers for Spectral Classification from Tikhoff Images.

Transfer from	Number of stars in overlap region	Probable error (subclasses)
Area C to B	30	3.2
Area B to A	29	2.9
Top to bottom of Area A	38	2.9

Table 3

Comparison of the Classifications of Two Independent Observers Listed by Areas.

Area	Number of stars measured by two observers	Probable error (subclasses)
A	128	3.0
B	46	3.4
C	1350	3.5

In addition, 1524 stars scattered over the entire area of the survey were classified by two independent observers. The probable error determined from the residuals of the two classifications is 3.4 subclasses. No

Table 4

Comparison of Our Spectral Classification and Photometry with Hardie and Seyfert.

BD Number	MK Sp	Tikhoff Estimate	Coyne m_{pg}	Coyne V	Hardie and Seyfert V	Hardie and Seyfert Vo	BD Number	MK Sp	Tikhoff Estimate	Coyne m_{pg}	Coyne V	Hardie and Seyfert V	Hardie and Seyfert Vo
35°4851	A0	A0	11.28	11.39	11.28	10.9	37°4650	A1	A2	9.69	9.77	9.92	9.5
36°4863	A2	B	9.55	9.60	9.11:	8.8:	37°4654	A0	B	9.96	10.07	10.24	10.0
36°4864	A1	A2	10.51	10.59	10.55	9.5	37°4655	A6	A5	9.51	9.45	9.66	9.4
36°4868	B9	B	10.34	10.51	10.50	10.1	37°4659	B8	B	9.73	9.93	10.14	9.8
36°4869	A1	B	10.19	10.27	10.01	8.8	38°4786	A0	B	9.60	9.71	9.59	9.4
36°4871	A1	B	9.75	9.83	9.74	9.2	38°4833	A5	A0	9.50	9.46	9.12	8.9
36°4881	A3	B	10.09	10.11	10.06	9.5	38°4834	B9	B	9.71	9.88	9.58	9.2
36°4884	B9	B	10.17	10.34	10.40	9.9	38°4837	A0	B	10.77	10.88	10.76:	10.3:
36°4896	A1	B	9.77	9.85	9.68	9.4	38°4849	B7:	B	9.11	9.34	8.66	8.3
36°4910	A0	B	9.70	9.81	9.88	9.6	38°4852	B9	B	9.66	9.83	9.08	8.6
36°4912	A0	B	10.14	10.25	10.24	9.9	38°4859	A0	A0	9.67	9.78	9.60	9.2
36°4917	A5	B	9.63	9.59	9.80:	9.5:	38°4883	B8	B	9.61	9.81	9.48	9.1
36°4922	B8	B	9.40	9.60	9.24	8.9	39°4861	A5	A0	10.5	10.46	10.92	10.9
36°4930	B9	B	10.42	10.59	10.24	9.7	39°4862	B9	A7	9.40	9.57	9.76	9.4
36°4932	A3	B	9.65	9.67	9.10	8.4	39°4868	A3	B	9.2	9.22	9.61	9.5
37°4598	B7	A3	9.92	10.15	10.15	9.8	39°4886	B7	B	8.18	8.41	8.52	8.2
37°4607	A3	A0	10.64	10.66	10.97	10.7	39°4890	B8	A0	9.23	9.43	9.49	9.3
37°4626	A5	B	10.48	10.44	10.85	10.8	39°4894	A2	B	9.15	9.20	9.03	8.8
37°4627	A5	A0	10.76	10.72	10.82	10.5	39°4907	B9	A0	9.62	9.79	10.13	9.9
37°4632	A0	B	9.53	9.64	9.84	9.6	39°4917	A1	B	9.71	9.79	9.94	9.7
37°4635	A3	B	10.40	10.42	10.50	9.9	39°4920	B8	A0	9.68	9.88	9.94	9.6
37°4636	A0	B	9.72	9.83	10.09	9.8	39°4926	B8p	B	9.42	9.62	9.28	8.6
37°4637	A2	B	9.71	9.76	9.51	8.7	39°4943	A1	B	10.03	10.11	9.99	9.9
37°4638	A0	B	10.46	10.57	10.70	10.2	39°4945	B8::	A0	11.27	11.47	11.44:	11.2:
37°4640	A1	B	9.77	8.85	9.97	9.7	40°4845	B7	B	8.94	9.17	9.09	8.7
37°4648	B8	B	9.70	9.90	9.77	9.4	40°4922	A5	A2	10.83	10.79	10.48	10.1

systematic difference was detected. The comparison of the classifications made by these two independent observers for areas A, B, and C (see Figure 1) is given in Table 3. In no case was a trend of residuals with spectral classes detected. Table 3 is a further indication that there is no loss in accuracy by transfers from plate to plate. The probable error, therefore, of the tie-in to the Bergedorfer classification system is about 3 subclasses for the total area of the sky surveyed.

Hardie and Seyfert have assigned MK spectral types to 77 A and B stars in area A. A comparison between their MK classification and our Tikhoff classification, transformed to MK types via Table 1, is given for 52 of these stars in columns 2, 3, 9, and 10 of Table 4. The remainder of Table 4 concerns photometry and will be referred to later. It is not possible from the Tikhoff images to distinguish among spectral types earlier than B9. Our classification "B", therefore, refers to all stars earlier than A0. Now, the Tikhoff classifications in area A are the result of three transfers over paired plates. Table 4 shows that this transfer is accurate with the probable error quoted and that the assumption of uniform reddening, at least for these early type stars, is valid. Unfortunately, MK classifications of later type stars in this field and in the magnitude range of our survey are not now available.

Magnitudes for virtually all stars were determined from photometric measurements of images on plate reproductions of the Palomar Sky Survey with the Cuffey-type astrophotometer of GSFC. Magnitudes for a few stars which had nonmeasurable images on the Palomar plates were determined by eye estimates of the images on the Tikhoff plates.

The astrophotometer used was built for GSFC by Astro Mechanics, Inc., Austin, Texas, and is a precision instrument designed to measure star brightness directly from stellar photographic plates. It is a double-beam design with null balance (see Figure 2). The measuring beam passes

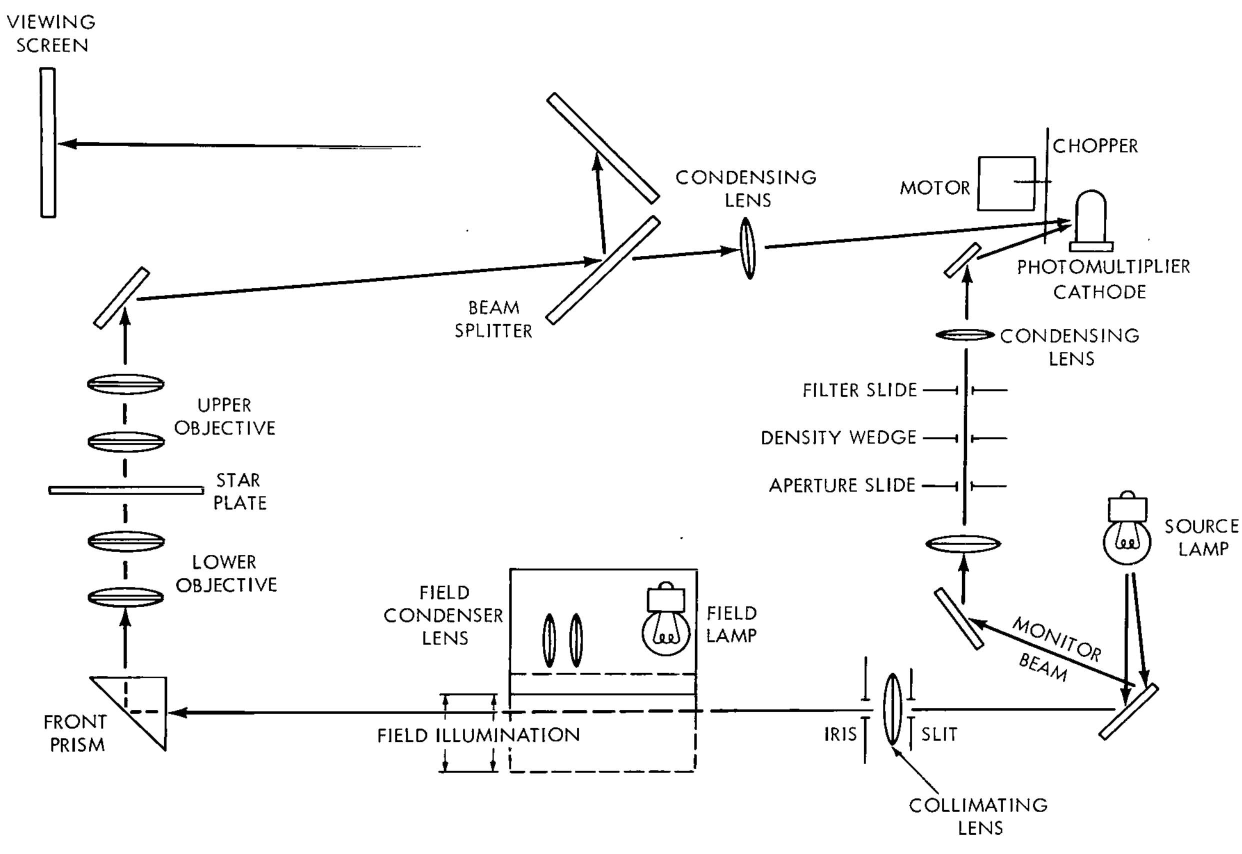

Figure 2—Optical schematic of astrophotometer.

through a slit, a collimating lens, an iris diaphragm, and an objective lens (lower objective) which forms an image of the iris on the emulsion surface of the stellar plate. This image of the iris on the photographic plate is picked up by an upper objective lens and is projected on the viewing screen by means of a beam splitter. Part of the measuring beam striking the beam splitter passes through to the condensing lens and then through the mechanical chopper; it then strikes the upper half of the photomultiplier cathode (931-A). For inspection, identification, and centering of a star image, a sizable area of the star plate may be viewed by shifting the beam from the field lamp into the path of the measured beam, which illuminates the area (of the star plate) centered between the upper and lower objectives. When the field beam is moved out of the path of the measuring beam, the viewer sees only the field area controlled by the iris for a single star measurement.

The monitoring beam emitted by the source lamp is attenuated by a filter slide having two fixed density plates and by a variable-density wedge. Six apertures in a linear-slide plate control the spot size of the monitoring beam. This beam passes through two lenses and the mechanical chopper to the lower portion of the photomultiplier cathode. The output of the photomultiplier is then fed to the amplifier and null meter. The diameter of the iris aperture, which is the essential measuring element, can be varied from about 0.040 to 1.35 inches. When the measuring beam is balanced to the same intensity as the monitoring beam, a reading of the iris aperture is taken by means of the counter located below the viewing screen.

Because we wish to compare our star counts in given spectral class and magnitude intervals with counts available in the Bergedorfer Spektraldurchmusterung for nearby areas of the sky, we have standardized our magnitudes to those of the Bergedorfer Spektraldurchmusterung for Selected Area 42. The Bergedorfer magnitudes are on the International Photographic System. Table 5 presents a comparison of the Bergedorfer with the Henry Draper and Mt. Wilson Catalogs (see Van Rhijn, 1938).

Reproductions of five Palomar plates (listed in Table 6) were required to cover the area of our survey; Figure 3 shows their distribution over the area of the survey. Palomar plate 537 overlaps Selected Area 42 and all other Palomar plates used in this survey. The following procedure was used for transferring the magnitude sequence from Selected Area 42 over the total area of our

Table 5

Comparison of Photographic Magnitude Systems.

m_{pg} (Bergedorfer)	Δm (Mt. Wilson - Bergedorfer)	Δm (HD - Bergedorfer)
<10.0	+0.25	+0.22
10.0 - 11.0	+0.03	+0.12
11.0 - 12.0	+0.01	+0.02
>12.0	-0.01	+0.06

Table 6

List of Palomar Plates Used.

Palomar Plate Number	Plate Center (1855)	
	α	δ
599	$22^h\ 06^m$	+48°
590	22 40	48
537	22 30	42
778	22 24	36
838	22 52	36

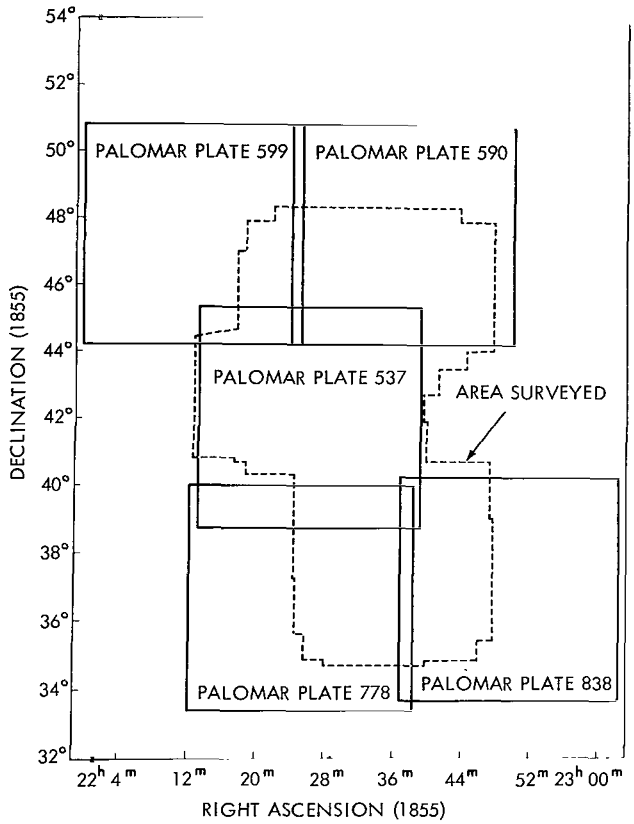

Figure 3—Location of Palomar plates.

Table 7

Distribution by Spectral Type of Stars Used in Photometric Calibration.

Spectral Class	Number of Stars in SA 42 Used for Calibration
Earlier than A0	24
A0 - A4	44
A5 - F5	61
F5 - G5	167
Later than G5	90
Total	386

survey. Photometric measurements were made on Palomar plate 537 of the 386 stars that are in Selected Area 42 and have magnitudes in the Bergedorfer catalog. The relationship of these photometric measurements to the Bergedorfer magnitudes was determined. Table 7 gives the distribution of these stars according to spectral class. Separate solutions were made for the relationship of Bergedorfer magnitudes to photometric measurements for these different spectral class intervals; there was no evidence of dependence on spectral class. On the other hand, magnitude-dependence does exist, and it was found that the best calibration was obtained by two straight-line solutions: one for $m_{pg} \geq 9.5$ and one for $m_{pg} < 9.5$. Accordingly, least-squares solutions yielded the following relationships of the photometric readings on Palomar plate 537 to the Bergedorfer magnitudes, m_{pg}:

$$m_{pg} = 0.006168\, pr_{238} - 9.939,\ m_{pg} \geq 9.5,$$
$$m_{pg} = 0.00347\, pr_{537} - 1.152,\ m_{pg} < 9.5.$$

The probable error associated with the determination of magnitudes from these equations is $0^m_.101$. Furthermore, the photometric readings on all other plates were reduced to photometric readings on Palomar plate 537 by measures of stars in the overlap region of each of the other Palomar plates with plate 537. This was done separately for each of the other four plates. A straight-line solution was found for the relationship of the readings on each of the plates to the readings on plate 537. Table 8 contains the data on these transfers. The probable error listed in column 3 has been multiplied by the factor 0.006168 to put it on a magnitude scale. In the course of this investigation the astrophotometer was returned to the shop for repairs. Approximately 35 percent of the photometric measurements were made before this time. The measurements before and after these repairs were made by two different observers, and in the course of the repairs the scale factor of magnitudes per unit photometer reading was decreased by a factor of 2 or 3. Essentially, therefore, we have two different photometric systems. From a group of 72 stars measured on both systems, a straight-line conversion was found. The associated probable error for this transfer is $0^m.084$.

It is to be noted that the plates of the Palomar Sky Survey do not overlap by more than about 0.6 degree, or about 3.2 cm; thus the plate transfers necessarily had to be made near the plate edge. The following test for a distance-from-center effect on the photometry was made: Palomar plate 590 is the only one which overlaps sufficiently with Selected Area 42, so that a group of standard stars is available both toward the center and toward the edge of the plate. Therefore, a photometric equation relating m_{pg} to photometric readings was determined separately for two groups of stars defined by the parameters given in Table 9. The photometric equations were identical within the accuracy of the photometry. Our conclusion is that the average probable error to be associated with the magnitude measurements in this survey is approximately $0^m.100$.

Table 8

Data for Transfer of Photometric Measurements on Palomar Plates.

Palomar Plate Number	Number of stars measured in overlap with P. P. 537	Probable error (photographic magnitudes)
599	46	$0^m.083$
590	30	0.115
778	47	0.113
838	47	0.077

Table 9

Groups of Stars Used for Investigation of Edge Effect in Photometry.

Group	Number of Stars	Distance from Plate Center (Degrees)	Distance from Edge		Area Deg^2
			Deg	Cm	
1	24	2.0	2.0	10.7	0.5
2	16	3.5	0.4	2.1	0.5

Photoelectric magnitudes have been determined by Hardie and Seyfert (1959) for a select number of the brighter A and B stars in our area A. Table 4 presents a comparison of their V magnitudes with V magnitudes determined from our photometry. Columns 4 and 11 list our photographic magnitudes; columns 5 and 12, our V magnitudes determined by the following equation (Allen, 1963):

$$V = m_{pg} - (B-V) + 0.11.$$

Columns 6 and 13 list the Hardie and Seyfert magnitudes uncorrected for absorption; columns 7 and 14 list the Hardie and Seyfert magnitudes corrected for absorption. The differences support the quoted probable error of our photometry, $0^m.100$. Note that these stars are at the bottom of the area we have surveyed and that the photometry has involved transfers from Selected Area 42 at the top of the area.

Comparison was also made with the photometric and the spectral classification systems of Ramberg (1957). For 93 stars of spectral type earlier than G6, the average residual of the photographic magnitudes was $0^m.15$. The difference is larger for later spectral types. For 180 stars of all spectral types, the average residual in spectral classes was 3 subclasses.

It would be interesting to know what accuracy would have been obtained for our spectral classifications had we photometered the red Palomar plates and used color equivalents from the blue and red Palomar magnitudes. If we assume the same probable error for the photometry of the red Palomar plates as we obtained for the blue plates ($0^{m}.1$), the probable error for a color index on the photovisual system would be about $0^{m}.14$, which is equivalent to about 5 subclasses for spectral types G6 and earlier. This suggests that colors determined by photographic photometry of red and blue Palomar Sky Survey plates would give less accurate results than does the Tikhoff method as we applied it for spectral types G6 and earlier.

RESULTS AND CONCLUSIONS

The results of this survey are presented in Tables 10 through 16. The format of each table is an array giving counts of stars for each half-magnitude interval (vertical) and spectral class intervals of 5 subclasses (horizontal). The dotted line that runs horizontally through each array indicates the limiting magnitude of this survey. The boxes in each array indicate the approximate location of the zero-age main sequence for each spectral class interval. Table 17 gives the information used for drawing these boxes. For each spectral class listed in column 1, the color and absolute visual magnitudes for the zero-age main sequence are given in columns 2 and 3, respectively (Blaauw, 1963). The corresponding apparent photographic magnitude for main-sequence

Table 10

Counts of Stars in Areas A, B, and C of Lac OB1.

AREA A	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4	1								
8.5– 8.9	2								
9.0– 9.4	9	3	2				2		
9.5– 9.9	44	17	8	1	3	3	7		3
10.0–10.4	43	19	4	12	6	14	11	8	2
10.5–10.9	26	59	28	19	16	15	32	8	4
11.0–11.4	10	74	35	31	25	24	33	18	9
11.5–11.9	2	67	37	16	41	45	46	27	9
12.0–12.4		25	17	14	18	24	37	14	11
12.5–12.9			2	1	4	8	15	12	5
13.0–13.4						1	1	5	1
13.5–13.9							1		
TOTAL	137	264	133	94	113	134	185	92	44
									1196

Table 10 (continued)

AREA B

	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4									
8.5– 8.9	3	1		1	1				
9.0– 9.4	17	4	2	2		1	2		
9.5– 9.9	34	13	5	6	11	6	10	4	
10.0–10.4	12	29	7	7	9	2	14	7	7
10.5–10.9	7	41	14	10	14	19	15	8	6
11.0–11.4	3	53	17	28	24	17	27	16	5
11.5–11.9	2	26	39	18	29	25	32	27	4
12.0–12.4		4	7	7	15	20	48	23	12
12.5–12.9		1		1	6	3	18	13	13
13.0–13.4				1			4	3	7
13.5–13.9								1	1
TOTAL	78	172	91	81	109	93	170	102	55
									951

AREA C

	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4									
8.5– 8.9	5							1	1
9.0– 9.4	13	6	3	4					
9.5– 9.9	41	19	5	3	4	3	8	10	4
10.0–10.4	19	27	10	10	14	5	19	18	4
10.5–10.9	10	71	15	24	18	20	20	27	10
11.0–11.4	5	95	36	36	17	30	53	34	23
11.5–11.9	8	38	21	23	17	45	79	66	35
12.0–12.4	3	11	5	4	13	30	62	60	43
12.5–12.9	1	1	1	1	2	4	17	40	29
13.0–13.4							2	4	8
13.5–13.9								1	
TOTAL	105	268	96	105	85	137	260	261	157
									1474

Table 11

Number of Stars Per 12.25 deg^2 in Area A.

	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4	0.36								
8.5– 8.9	0.71								
9.0– 9.4	3.22	1.07	0.71				0.71		
9.5– 9.9	15.73	6.08	2.86	0.36	1.07	1.07	2.50		1.07
10.0–10.4	15.37	6.79	1.43	4.29	2.14	5.00	3.93	2.86	0.71
10.5–10.9	9.29	21.09	10.01	6.79	5.72	5.36	11.44	2.86	1.43
11.0–11.4	3.57	26.45	12.51	11.08	8.94	8.58	11.80	6.43	3.22
11.5–11.9	0.71	23.95	13.23	5.72	14.65	16.08	16.44	9.65	3.22
12.0–12.4		8.94	6.08	5.00	6.43	8.58	13.23	5.00	3.93
12.5–12.9			0.71	0.36	1.43	2.86	5.36	4.29	1.79
13.0–13.4						0.36	0.36	1.79	0.36
13.5–13.9							0.36		

Table 12

Number of Stars Per 12.25 deg^2 in Area B.

	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4									
8.5– 8.9	1.68	0.56		0.56	0.56				
9.0– 9.4	9.51	2.24	1.12	1.12		0.56	1.12		
9.5– 9.9	19.01	7.27	2.80	3.36	6.15	3.36	5.59	2.24	
10.0–10.4	6.71	16.22	3.91	3.91	5.03	1.12	7.83	3.91	3.91
10.5–10.9	3.91	22.93	7.83	5.59	7.83	10.63	8.39	4.47	3.36
11.0–11.4	1.68	29.64	9.51	15.66	13.42	9.51	15.10	8.95	2.80
11.5–11.9	1.12	14.54	21.81	10.07	16.22	13.98	17.90	15.10	2.24
12.0–12.4		2.24	3.91	3.91	8.39	11.18	26.84	12.86	6.71
12.5–12.9		0.56		0.56	3.36	1.68	10.07	7.27	7.27
13.0–13.4				0.56			2.24	1.68	3.91
13.5–13.9								0.56	0.56

Table 13

Number of Stars Per 12.25 deg^2 in Area C.

m_{pg}	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4									
8.5– 8.9	1.74							0.35	0.35
9.0– 9.4	4.52	2.09	1.04	1.39					
9.5– 9.9	14.25	6.60	1.74	1.04	1.39	1.04	2.78	3.48	1.39
10.0–10.4	6.60	9.39	3.48	3.48	4.87	1.74	6.60	6.26	1.39
10.5–10.9	3.48	24.68	5.21	8.34	6.26	6.95	6.95	9.39	3.48
11.0–11.4	1.74	33.02	12.51	12.51	5.91	10.43	18.42	11.82	8.00
11.5–11.9	2.78	13.21	7.30	8.00	5.91	15.64	27.46	22.94	12.17
12.0–12.4	1.04	3.82	1.74	1.39	4.52	10.43	21.55	20.86	14.95
12.5–12.9	0.35	0.35	0.35	0.35	0.70	1.39	5.91	13.91	10.08
13.0–13.4							0.70	1.39	2.78
13.5–13.9								0.35	

Table 14

Ratio of Counts per Deg^2 in Area A to Counts per Deg^2 in Area B.

	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4									
8.5– 8.9	– 0.43								
9.0– 9.4	⊖ 0.34	– 0.48	0.64				0.64		
9.5– 9.9	0.83	0.84	1.02	-0.11	- 0.17	- 0.32	⊖0.45		
10.0–10.4	⊕ 2.29	⊖ 0.42	⊖ 0.37	1.10	⊖0.43	+ 4.47	0.50	0.73	- 0.18
10.5–10.9	⊕ 2.37	0.92	1.28	1.21	0.73	0.50	1.36	0.64	- 0.43
11.0–11.4	+ 2.13	0.89	1.32	0.71	0.67	0.90	0.78	0.72	1.15
11.5–11.9	0.64	⊕ 1.65	0.61	0.57	0.90	1.15	0.92	0.64	1.44
12.0–12.4		⊕ 3.99	⊕ 1.55	1.28	0.77	0.77	⊖0.49	⊖0.39	0.59
12.5–12.9				0.64	- 0.43	+ 1.70	0.53	0.59	⊖0.25
13.0–13.4							- 0.16	1.07	- 0.09
13.5–13.9									

– Ratio < 0.50
+ Ratio > 0.50
O Raw count of stars in each area ≥ 5 (See Table 10), and ratio < 0.50 or > 1.50

Table 15

Ratio of Counts per Deg^2 in Area A to Counts per Deg^2 in Area C.

m_{pg}	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4									
8.5– 8.9	- 0.41								
9.0– 9.4	0.71	0.51	0.69						
9.5– 9.9	1.10	0.92	+ 1.64	- 0.35	0.77	1.03	0.90		0.77
10.0–10.4	⊕ 2.33	0.72	⊖ 0.41	1.23	⊖0.44	⊕2.88	0.60	⊖0.46	0.51
10.5–10.9	⊕ 2.67	0.85	⊕ 1.92	0.81	0.91	0.77	⊕1.65	⊖0.30	- 0.41
11.0–11.4	⊕ 2.06	0.80	1.00	0.89	⊕1.51	0.82	0.64	0.54	⊖0.40
11.5–11.9	- 0.26	⊕ 1.81	⊕ 1.81	0.72	⊕2.48	1.03	0.60	⊖0.42	⊖0.26
12.0–12.4		⊕ 2.34	⊕ 3.49	⊕ 3.60	1.42	0.82	0.61	⊖0.24	⊖0.26
12.5–12.9			+ 2.06	1.03	+ 2.06	+ 2.06	0.91	⊖0.31	⊖0.18
13.0–13.4							0.51	1.29	- 0.13
13.5–13.9									

Table 16

Ratio of Counts per Deg^2 in Area A to Average of Counts per Deg^2 in Areas B and C.

m_{pg}	B	A0–A4	A5–A9	F0–F4	F5–F9	G0–G4	G5–G9	K0–K4	K5–
8.0– 8.4									
8.5– 8.9	- 0.42								
9.0– 9.4	⊖ 0.46	0.50	0.66				1.28		
9.5– 9.9	0.95	0.88	1.26	- 0.16	- 0.28	- 0.49	0.60		+ 1.54
10.0–10.4	⊕ 2.31	0.53	⊖ 0.39	1.16	⊖0.43	+ 3.50	0.54	0.56	- 0.27
10.5–10.9	⊕ 2.51	0.89	⊕ 1.53	0.97	0.81	0.61	1.49	⊖0.41	- 0.42
11.0–11.4	⊕ 2.09	0.84	1.14	0.79	0.92	0.86	0.70	0.62	0.60
11.5–11.9	- 0.37	⊕ 1.73	0.91	0.63	1.32	1.09	0.72	0.51	⊖0.45
12.0–12.4		⊕ 2.95	⊕ 2.15	⊕ 1.89	1.00	0.79	0.55	⊖0.30	⊖0.36
12.5–12.9			+ 4.11	0.79	0.71	+ 1.86	0.67	⊖0.41	⊖0.21
13.0–13.4							- 0.24	1.16	- 0.11
13.5–13.9									

- Ratio < 0.50
+ Ratio > 1.50
O Raw count of stars in each area ≥ 5 and ratio < 0.50 or > 1.50

stars is listed in column 4 and determined in the following manner: We adopt a distance modulus of $m_v - M_v = 8^m_.4$ and a total photographic absorption of $A_{pg} = 0^m_.4$. We then determine m_{pg} from the following equation taken from Allen (1963):

$$m_{pg} = m_v + (B-V) - 0.11 \ .$$

Table 10 gives the raw counts for the number of stars in each of the areas A, B, and C (see Figure 1). Tables 11 to 13 give the number of stars per 12.25 deg² for these respective areas. The normalization factor of 12.25 deg² was selected for convenient comparison with counts in the Bergedorfer Spektraldurchmusterung. Table 14 lists the ratio of the counts per deg² in area A to the counts per deg² in area B, and Table 15 lists a similar ratio for areas A and C. Table 16 lists the ratio of the counts per deg² in area A to the average of the counts per deg² in areas B and C. In Tables 14, 15, and 16 the following notation is used to facilitate analysis. To the left of each column we make the following designations:

Table 17

Photographic Magnitudes for Main Sequence Stars at the Distance of the Association Lac OB1.

Spectral Class	B-V	M_v	m_{pg}
B0	-0.30	-3.30	+5.09
B9	-0.06	+1.04	+9.67
A0	0.00	+1.55	+10.24
A5	+0.15	+2.25	+11.09
F0	+0.33	+3.10	+12.12
F5	+0.45	+3.83	+12.97
G0	+0.60	+4.80	+14.09
G5	+0.68	+5.28	+14.65
K0	+0.81	+5.94	+15.44
K5	+1.18	+7.56	+17.43

- \- if the ratio is less than 0.5,
- \+ if the ratio is greater than 1.5,
- 0 if the raw counts for each of the areas included in the ratio is greater than 5 stars and the ratio < 0.5 or > 1.5.

An examination of Tables 14, 15, and 16 leads to the following conclusions concerning the relative distributions in area A (which is almost coincident with Blaauw's concentrated area) and areas B and C, in the dispersed area of the association. Area A shows a deficiency of bright B stars and an excess of faint B stars with respect to areas B and C. If our estimate is correct that a B9V star in the association will have $m_{pg} = 9^m_.67$, the deficiency of bright B stars occurs on or above the main sequence; while the excess occurs about a magnitude or so below the main sequence. This is difficult to understand. However, there are various possible explanations. The main sequence may occur at fainter magnitudes than we have estimated. If this is the case, the respective counts in areas A, B, and C would tend to corroborate Blaauw's evolutionary hypothesis (Blaauw, 1958) that the bright stars in the dispersed area of the association have evolved off the main sequence. On the other hand, the effect may actually represent the distribution of foreground stars. A third possibility is that a significant proportion of the stars classified as B may actually be early A type stars. A comparison of columns 2, 3, 9, and 10 of Table 4 tends to support this possibility. As mentioned previously, the classification "B" indicates all stars earlier than A0. The probable error for the classification of late B and early A stars is about 3.5 subclasses. If this last alternative is the true one, area A has with respect to areas B and C and excess of early A stars on and slightly below the main sequence and a deficiency of A stars above the main sequence. Apart from this alternative, area A already shows an excess of A stars below the main sequence. Indeed, the excess of A stars near the main sequence in area A appears to extend to late A and early F stars. This, at least in appearance, is the same evolutionary trend discussed by Blaauw for O and B stars: the concentrated part of the association contains a larger number of main-sequence stars. This trend appears to extend now to A and perhaps early F stars. We must emphasize that this is only an apparent effect. Further observation,

Table 18

Galactic Coordinates for the Center of the Areas Studied.

Area	ℓ_{II}	b_{II}
A	95°	-17°
B	97°	-13°
C	100°	-10°
SA 43	113°	-16°
SA 67	98°	-27°

Table 19

Number of Stars Per 12.25 deg ^{2} in Selected Area 43.

	B0-5	B6-9	A0-4	A5-9	F0-4	F5-9	G0-4	G5-9	K0-4	K5-9
$0^m.0-8^m.5$	3	4	2	1		1		2		
8.5- 9.0		1	2	1		2				2
9.0- 9.5	1	2	5	1	4	4	1	6	2	1
9.5-10.0		6	5	4	4	8		4	3	1
10.0-10.5		5	10	5	12	6	10	8	4	2
10.5-11.0		2	5	1	7	18	12	13	15	5
11.0-11.5			9	11	8	48	23	13	20	4
11.5-12.0		2	16	15	13	37	51	21	24	4
12.0-12.5			6	13	7	39	70	22	21	4
12.5-13.0		1	11	32	7	111	278	94	73	12
13.0-13.5	1		5	11	5	78	273	71	56	13
13.5-14.0								1		
TOTAL	5	23	76	95	67	352	718	255	218	48

especially of radial velocities and proper motions, will be necessary in order to determine whether this is a true effect within the association or whether it is simply attributable to distributions among the field stars. With respect to spectral types later than F4, area C has a deficiency of F5 to F9 stars in the magnitude range $11^{m}.0$ to $12^{m}.5$ and an excess of stars later than K0 and fainter than $10^{m}.0$. These are undoubtedly effects in the distribution of the field stars. It should be noted that Howard (1958), from star counts in the Henry Draper Catalog, found an excess of A stars at apparent visual magnitudes 9 to 10 in an area two-thirds of which is covered by our area C. Our analysis indicates that at fainter magnitudes (11 to 13) our area A, which contains Blaauw's concentrated region, has on the average two times as many A stars as area C, which contains Howard's A star excess. It is at these fainter magnitudes that a noticeable differential effect of the A star distribution over the area of the association appears.

We now wish to compare the counts in our areas with those in Selected Areas 43 and 67. The galactic coordinates for the center of each of our areas A, B, and C and for Selected Areas 43 and 67 are given in Table 18. The counts for Selected Areas 43 and 67, reproduced from the Bergedorfer Spektraldurchmusterung, are given in Tables 19 and 20. Compare these with Tables 11, 12, and 13. For the total area of our survey there is an excess of A0 to A4 stars, the counts being on

Table 20

Number of Stars per 12.25 deg^2 in Selected Area 67.

	B0-5	B6-9	A0-4	A5-9	F0-4	F5-9	G0-4	G5-9	K0-4	K5-9
$0^{m}.0$- $8^{m}.5$			4		4	1		2	2	1
8.5- 9.0			3		2		2	1	2	1
9.0- 9.5						3	3	3	2	
9.5-10.0			3		1	4	1	6	3	
10.0-10.5			5		2	12	5	7	5	2
10.5-11.0			2	1	3	19	9	13	5	2
11.0-11.5			7	3	4	26	19	20	20	3
11.5-12.0			3	2	2	15	30	35	23	3
12.0-12.5			5	6	8	21	29	58	21	3
12.5-13.0			7	7	7	34	81	98	31	5
13.0-13.5			2	4	8	31	113	113	18	10
13.5-14.0								1		
TOTAL			41	23	41	166	292	357	132	30

the average two to three times the counts in Selected Area 43 and three times the counts in Selected Area 67 in the range $10^{m}.5 < m_{pg} < 12^{m}.0$. Another outstanding feature is the great paucity of stars later than F5 and fainter than about $m_{pg} = 9^{m}.5$. This paucity of stars later than F5 is also evident when comparison is made with Selected Area 67, which is 10 degrees or more further from the galactic plane than the areas of our survey.

In fact, if we compare counts in area A (which is centered at $\ell^{II} = 95°$, $b^{II} = -17°$) with counts in the Bergedorfer catalog for a galactic latitude zone of -15° (which includes counts from Selected Areas 20, 21, 22, 42, and 43 and extends from $\ell_{II} = 102°$ to $143°$), we find the same evidence for a lack of late type stars in area A. This is indicated in Table 21, which lists the ratio of the counts in area A to those in the galactic latitude zone, $b_{II} = -15°$. The same trend is indicated for areas B and C.

Table 21

Ratio of the Number of Stars per deg^2; Area A Compared with Latitude Zone, $b_{II} = -15°$, of Bergedorfer Catalog.

	B-A4	A5-F4	F5-G4	G5-K4
8.5- 9.4	0.38			
9.5-10.4	1.40	0.48	0.47	0.41
10.5-11.4	1.39	1.16	0.30	0.52
11.5-12.4	0.78	0.44	0.20	0.37

SUGGESTIONS

The tenative conclusions that we have drawn with respect to the clustering of A stars near the main sequence in area A suggests that, among the several further observational problems indicated by this survey, studies be first made of area A that would include the following:

1. Objective prism classification of all A stars.
2. Magnitude determinations of these A stars either photoelectrically or, if this is not feasible, photographically using a good photoelectric sequence.
3. Radial-velocity determinations using, perhaps, the Fehrenbach prism method.
4. Proper motions (first epoch plates 30 to 40 years old are, we believe, available in the Harvard College Observatory Plate Library).

Our counts (see Table 10) indicate that area A contains a total of 397 A stars in the range $9^{m}.0 < m_{pg} < 13^{m}.0$. It is hoped that the projected study will determine association membership and provide a clearer picture of the dwarf A star population in Lac OB1.

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